MODIS
Terra Coccolith Products
Data Quality Summary
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Investigation: MODIS

Data Product: Coccolith Products (MOD25)

Data Set: Terra

Data Set Version: 3

Nature of the products

There are three individual products related to coccolithophores: coccolith pigment concentration (C, MODIS Ocean Parameter #20), coccolith concentration (C_{cc}, MODIS Ocean Parameter #21), and suspended calcium carbonate concentration (PIC, MODIS Ocean Parameter #22). All three products are based on normalized water-leaving radiance (nL_w) at 443nm (MODIS Band 9/MODIS Ocean parameter 2) and 551 nm (MODIS Band12/MODIS Ocean parameter 5). The accuracy of the coccolithophore products is subject to the quality flags for the above radiance bands. The three products will be presented together, as they are highly inter-related.

The detailed theoretical basis of the Coccolith/Suspended Calcite Algorithm can be found at the MODIS site http://modarch.gsfc.nasa.gov/MODIS/ATBD/atbd_mod23.pdf. Briefly, variations in the coccolithophore calcite concentration influence the nL_w's at 443 and 551 nm in significantly different manners, depending on the concentration of phytoplankton pigments. The algorithm uses a two-parameter model for nL_w (Gordon et al., 1988) and solves for the particulate backscattering and pigment concentrations given $nL_w(443)$ and $nL_w(551)$. The calcite-specific backscattering coefficient $(b_b)^*_{PIC}$ is then used to estimate the detached coccolith concentration and the calcite concentration.

Predicted Data Accuracy

Since the two-band PIC algorithm uses absolute values of the water-leaving radiances, it is more susceptible to errors in atmospheric correction than the usual ocean color algorithms that employ radiance ratios. Thus, atmospheric correction can be an important source of error over and above the inherent error in the algorithm due to natural variability. In addition errors in sensor calibration can also cause errors in the recovered water-leaving radiance. (See MODIS Normalized Water-leaving Radiance Algorithm Theoretical Basis Document, by H.R. Gordon, for a discussion, with numerical examples, of atmospheric correction errors and the influence of sensor calibration errors on nL_w. The site is http://modarch.gsfc.nasa.gov/MODIS/ATBD/atbd_mod17.pdf.). We estimate that the error due to atmospheric correction will be small at $C_{cc} < 5 \times 10^9$ coccoliths m^{-3} for low pigment concentrations (C) and 10×10^9 to 15×10^9 coccoliths m^{-3} for C of 2 mg m^{-3}. Another potential source of error is the fact that the atmospheric correction algorithm assumes that $nL_w = 0$ for λ = 765 and 865 nm, i.e., in the near infrared (NIR). For sufficiently high coccolith concentrations this will be violated, which will degrade the atmospheric correction and therefore the retrieval of nL_w in

the blue and green, introducing more uncertainty in C_{cc}. However, thus far our field and laboratory studies suggest that the largest potential error is natural variability of the $(b_b)_{PIC}$ - C_{cc} relationship (Balch et al., 1999).

Validation Study Results

As this is a new product and Terra was only launched in December 1999, there are relatively few data sets available for validation, particularly for the coccolith and suspended calcite products. This is because coccolith concentration (or particulate inorganic carbon, calcium carbonate) is not frequently measured at sea, while the chlorophyll concentration is. In conjunction with the NASA SIMBIOS activities, much of our validation estimates comes from the Gulf of Maine, the site of frequent blooms of coccolithophores, and readily accessible from our laboratory. We also made some measurements in a Bering Sea coccolithophore bloom.

Initial estimates of accuracy have been made based on comparison to shipboard measurements. A significant bloom of coccolithophores occurred in the Bering Sea in the fall of 1997 (15 September) We enumerated coccolith and coccolithophore concentration from water samples collected by a NOAA research ship within the feature (56^o 56.24'N $\times$ 170^o 19.66'W; Samples by Dr. J. Napp; no PIC measurements were available). The MODIS sensor had not yet been launched, so we applied the two-band coccolith algorithm to a SeaWiFS image. The coccolith concentration at this station, in the top 12 m of the water column, was 3.6×10^{11} coccoliths m^{-3}, and the SeaWiFS-derived estimate was 3.0×10^{11} coccoliths m^{-3}.

A small bloom of coccolithophores occurred in the Gulf of Maine during summer 2000, which was sampled on several occasions. In this feature, we made atomic absorption measurements of suspended PIC and microscope enumeration of coccoliths and plated coccolithophores. We report the former here. For the days where the ship was on the west side of the MODIS swath (most accurate radiance retrievals), we report that the overall accuracy in the PIC determination was 0.2-3 mg PIC m^{-3}. (or in terms of coccolith concentration, 1 - 10×10^9coccoliths m^{-3}). However, if one pools all the calibration data made over various days (and hence incorporating the different atmospheric effects, then the accuracy degrades to ~3 mg PIC m^{-3}, or 15×10^9 coccoliths m^{-3}.

For the 36 km global data, there are no comparable sea-truth data available at this time, thus we compared the statistics of the global values with statistics of regional field surveys or global models. Good agreement was found between the models, surveys, and the MODIS-derived global mean PIC (all within ~ $\pm$ 1 mg PIC m^{-3}).

Globally, the coccolith pigment product is well correlated to the MODIS pigment product (MODIS Ocean Products 15). Regionally, within the Gulf of Maine, however, the correlation is best at high pigment concentrations; at low concentrations, coccolithophore pigment concentration is systematically less than the MODIS pigment value. Given that we expect most of the satellite-derived blooms of coccolithophores to be *E. huxleyi*, we also would expect the band-ratio algorithms to underestimate the pigment concentration for suspensions of these small coccoliths (Balch et al., 1989). Thus, we suggest using the MODIS pigment product for PIC values up to 5 mg PIC m^{-3}, above which, the coccolithophore pigment values should be used.

Data Flags

For the discussion of product flags, we first require that the common flags for level 0 and 1 products are all zero (acceptable) in order to process any of the coccolith products. The product quality level for the level 2, coccoliths, PIC concentration and coccolith pigment directly depends on the quality of the input radiance data. Therefore, these products will be assigned the minimum quality level of the input data (normalized water-leaving radiance products at 443nm and 551nm). For coccolith/PIC products, if PIC concentration is ≤ 0 or > 1000 mg PIC m^{-3}, then the product quality level for the coccolith/PIC products and coccolithophore pigment concentration will be assigned a quality level of 3 (worst). We suggest using the coccolith pigment product (product #20) rather than the MODIS pigment product (product #15), if PIC concentration > 5 mg PIC m^{-3}. Otherwise, the MODIS pigment should be used in preference to the coccolith pigment product (assuming that the quality level of the former is at least as good as the latter).

Cautions When Using Data

The coccolithophore data products should be treated as "preliminary", until more shipboard validation work can be done, and accuracy checked. In addition, the normalized water-leaving radiances that are used in the estimations are also "preliminary" and expected to improve significantly.

From the validation work done so far, if validation data are available on the same day as the MODIS measurements, the accuracy can be expected to be from 0.2 - 2 mg PIC m^{-3}. If no validation data are available, then one can assume a best-case accuracy of ± 3 mg PIC m^{-3}. Moreover, until all BRDF problems are resolved, we do not recommend using these MODIS coccolithophore data products unless they are from the western third of the MODIS swath. We also caution using these data from shallow ocean regions, particularly near carbonate banks (e.g. Grand Bahamas), where bottom reflectance will appear as a high-reflectance coccolithophore bloom (presumably such pixels would be flagged due to their shallowness). Moreover, near river mouths and in shallow waters, resuspended sediments (of non-calcite origin) may appear as high suspended calcite concentrations. Only use these data if the waters are sufficiently deep to not have such bottom resuspension or direct river impact. Beware that MODIS-derived coccolith concentrations assume that the coccoliths are from the prymnesiophyte, *E. huxleyi*. If this is not true, then inaccuracies will increase. Even when using the data in units of mg PIC m^{-3}, they nevertheless assume a constant backscattering cross-section for *E. huxleyi* , which is known to vary with the size of the calcite particle (Balch et al., 1999; Balch et al., 1996).

More information about the algorithm and inputs can be found in:

Esaias, W., et al., 1998, Overview of MODIS Capabilities for Ocean Science Observations, IEEE Transactions on Geoscience and Remote Sensing, vol. 36, no. 4, July 1998, pp. 1250-1265.

Planned Algorithm Improvements

As the normalized water-leaving radiances used in the estimations improve, a concomitant improvement in PIC is to be expected. Additionally, a three-band algorithm has been recently described for determining suspended calcite concentration (Gordon et al. 2001). This algorithm has the added advantage that chlorophyll does not interfere with the acquisition of the PIC. Validation checks are ongoing before the algorithm will be fully implemented within the MODIS data stream.

Referencing Data in Journal Articles

Results derived from this algorithm should cite the paper of Gordon et al. (1988) for the original discussion, and (Balch et al., 1999; Balch et al., 1996) for field data on the backscattering cross-section of calcite.

Citations

Balch, W.M., Drapeau, D.T., Cucci, T.L., Vaillancourt, R.D., Kilpatrick, K.A. and Fritz, J.J., 1999. Optical backscattering by calcifying algae--Separating the contribution by particulate inorganic and organic carbon fractions. Journal of Geophysical Research 104, 1541-1558.

Balch, W.M., Eppley, R.W., Abbot, M.R. and Reid, F.M.H., 1989. Bias in satellite-derived pigment measurements due to coccolithophores and dinoflagellates. Journal of Plankton Research 11, 575-581.

Balch, W.M., Kilpatrick, K., Holligan, P.M., Harbour, D. and Fernandez, E., 1996. The 1991 coccolithophore bloom in the central north Atlantic. II. Relating optics to coccolith concentration. Limnology and Oceanography 41, 1684-1696.

Gordon, H.R., G.C. Boynton, W.M. Balch, S.B. Groom, D.S. Harbour, and T.J. Smyth, Retrieval of Coccolithophore Calcite Concentration from SeaWiFS Imagery, *Geophys. Res. Lett.* **28**: 1587—1590, 2001.

Gordon, H.R., Brown, O.B., Evans, R.H., Brown, J.W., Smith, R.C., Baker, K.S. and Clark, D.K., 1988. A semianalytic radiance model of ocean color. Journal of Geophysical Research 93, 10909-10924.